

# Hubble Space Telescope Imaging of the Optical Transient Associated with GRB970508

E. Pian<sup>1</sup>, A. S. Fruchter<sup>2</sup>, L. E. Bergeron<sup>2</sup>, S. E. Thorsett<sup>3</sup>, F. Frontera<sup>1,4</sup>, M. Tavani<sup>5,6</sup>,  
E. Costa<sup>7</sup>, M. Feroci<sup>7</sup>, J. Halpern<sup>5</sup>, R. A. Lucas<sup>2</sup>, L. Nicastro<sup>1</sup>, E. Palazzi<sup>1</sup>, L. Piro<sup>7</sup>,  
W. Sparks<sup>2</sup>, A. J. Castro-Tirado<sup>8</sup>, T. Gull<sup>9</sup>, K. Hurley<sup>10</sup>, H. Pedersen<sup>11</sup>

## ABSTRACT

We report on Hubble Space Telescope (HST) observations of the optical transient (OT) discovered in the error box of the gamma-ray burst GRB970508. The object was imaged on 1997 June 2 with the Space Telescope Imaging Spectrograph (STIS) and Near-Infrared Camera and Multi-Object Spectrometer (NICMOS). The observations reveal a point-like source with  $R = 23.1 \pm 0.2$  and  $H = 20.6 \pm 0.3$ , in agreement with the power-law temporal decay seen in ground-based monitoring. Unlike the case of GRB970228, no nebulosity is detected surrounding the OT of GRB970508. We set very conservative upper limits of  $R \sim 24.5$  and  $H \sim 22.2$  on the brightness of any underlying extended source. If this subtends a substantial fraction of an arcsecond, then the  $R$  band limit is  $\sim 25.5$ . In combination with Keck spectra that show Mg I absorption and [O II] emission at a redshift of  $z = 0.835$ , our observations suggest that the OT

---

<sup>1</sup>Istituto di Tecnologie e Studio delle Radiazioni Extraterrestri, C.N.R., Via Gobetti 101, I-40129 Bologna, Italy

<sup>2</sup>Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA

<sup>3</sup>Joseph Henry Labs. and Dept. of Physics, Princeton University, Princeton, NJ 08544, USA

<sup>4</sup>Dip. Fisica, Università di Ferrara, Via Paradiso 12, I-44100 Ferrara, Italy

<sup>5</sup>Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027, USA

<sup>6</sup>Istituto di Fisica Cosmica e Tecnologie Relative, C.N.R., Via Bassini 15, I-20133 Milano, Italy

<sup>7</sup>Istituto di Astrofisica Spaziale, C.N.R., Via E. Fermi 21, I-00044 Frascati, Italy

<sup>8</sup>Laboratorio de Astrofísica Espacial y Física Fundamental, INTA, P.O. Box 50727, 28080 Madrid, Spain

<sup>9</sup>NASA/ Goddard Space Flight Center, Greenbelt, MD 20071, USA

<sup>10</sup>University of California Space Sciences Laboratory, Berkeley, CA 94720, USA

<sup>11</sup>Copenhagen University Observatory, Juliane Maries Vej 30, DK 2100 Copenhagen, Denmark

is located in a star-forming galaxy with total luminosity one order of magnitude lower than the knee of the galaxy luminosity function,  $L^*$ . Such galaxies are now thought to harbor the majority of star formation at  $z \sim 1$ ; therefore, these observations may provide support for a link between GRBs and star formation.

*Subject headings:* Cosmology: observations — galaxies: starburst — gamma rays: bursts — stars: formation

## 1. Introduction

Gamma-Ray Bursts (GRBs) were discovered over twenty-five years ago (Klebesadel, Strong, & Olson 1973), and are now detected by BATSE at a rate of about one per day (Meegan et al. 1996). Their energy sources and emission mechanisms are unknown, and their distance scale remains a matter of controversy (Lamb 1995; Paczyński 1995). The solution of this longstanding mystery may finally be near with the recent detection of long-wavelength counterparts to GRBs (Costa et al. 1997a; van Paradijs et al. 1997; Piro et al. 1997a).

On 1997 May 8.9 (UT) the Gamma-Ray Burst Monitor onboard the Italian-Dutch satellite BeppoSAX was triggered by a 15 s long transient event (Costa et al. 1997b) in the 40-700 keV energy range (peak flux  $F_\gamma = (5.6 \pm 0.7) \times 10^{-7} \text{ erg s}^{-1} \text{ cm}^{-2}$ ), which was detected also by one of the BeppoSAX Wide Field Cameras, with an intensity equivalent to 1 Crab unit in the 2-30 keV range (Costa et al. 1997b), by BATSE (Kouveliotou et al. 1997), and by Ulysses (Hurley 1997). Within the 3' error circle determined by the Wide Field Camera detection no other X-ray source was observed (Heise et al. 1997). Follow-up target-of-opportunity observations with the BeppoSAX Narrow Field Instruments in the 0.5-10 keV range on May 9.1, 11.8, 13.1 and 15.1 revealed a previously unknown X-ray source which declined in intensity by a factor of four (Piro et al. 1997b;c), supporting a possible identification of the transient as the X-ray counterpart of GRB970508.

An optical source was detected in the BeppoSAX Wide Field Camera error box with initial magnitude  $V = 21.5$  (Bond 1997). The next day, the source was seen to brighten by one magnitude. Positional confirmation and refinement was obtained at Palomar (Djorgovski et al. 1997) and from radio observations (Frail et al. 1997). UBVRI photometry of the OT by other observers at many sites was taken during the following days. In the R band, which is the best sampled, the flux was constant or slowly declining in the first 8 hours after the GRB, then it rose by a factor 5 in  $\sim 40$  hours. After a maximum on May 10.8, the brightness subsided monotonically with an approximately power-law temporal

dependence  $f(t) \propto (t - t_0)^{-p}$ , where  $t_0$  is the time of the GRB detection, with slope  $p = 1.17 \pm 0.04$  ( $1\sigma$ ), as determined through a weighted least-squares fit (reduced  $\chi^2 \simeq 0.6$ ) to the decaying portion of the light curve (see Figure 1, and the caption for references). This is reminiscent of the optical decline of GRB970228, which is generally well modeled by a temporal power-law of index  $p = 1.1$  (Fruchter et al. 1997).

The spectrum of the OT between 3500 and 8000 Å is well fit by a power-law  $f_\nu \propto \nu^{-\alpha_\nu}$  with  $\alpha_\nu \sim 1$  at all epochs for which simultaneous photometry is available in at least four filters, agreeing with spectrophotometry made at the Keck II telescope (Metzger et al. 1997a). This corresponds to a flat  $\nu f_\nu$  spectrum. Keck spectroscopy also reveals absorption systems at  $z = 0.767$  and  $0.835$  superposed on the continuum as well as [O II] line emission at  $z = 0.835$  (Metzger et al. 1997b). The absence of Lyman- $\alpha$  absorption forest and of a continuum decrement suggests that its redshift,  $z \lesssim 2.3$ . The presence of Mg I absorption and [O II] emission in the Keck spectrum suggest a line of sight through a dense interstellar medium; however, the only potential host galaxy detected from ground-based imaging is a faint blue object lying  $5''.2$  away from the OT (Djorgovski et al. 1997).

Here we present imaging using the newly deployed HST instruments STIS and NICMOS. These observations were designed to search for a host galaxy and to obtain late-time photometry of the OT of GRB970508. Data reduction and analysis are described in §2, the results are reported in §3 and discussed in §4.

## 2. Observations and data analysis

Four 1250-second exposures were obtained of the GRB970508 field using the STIS CCD in Clear Filter mode during 1997 June 2.52-2.66 (UT). In spite of the relatively short integration time, the high throughput and wide effective band-pass of the STIS CCD combined to make this one of the deepest images yet taken by HST – only about one magnitude shallower than the Hubble Deep Field in the F606W filter of the HST Wide Field and Planetary Camera (Williams et al. 1996). The four exposures were dithered to allow removal of hot pixels and to obtain the highest possible resolution. The images were bias subtracted, flat-fielded, corrected for dark current and calibrated by the newly created STIS pipeline. The final image (Figure 2) was created and cleaned of cosmic rays using the Variable-Pixel Linear Reconstruction technique (Fruchter & Hook 1997).

Four exposures of 514 seconds each were also made with the NICMOS Camera 2 on 1997 June 2.67-2.74 (UT). The four exposures were dithered using the NICMOS spiral dither pattern. The F160W filter (close to the standard near-infrared H band) was used as

this filter covers the wavelength range where the HST background light is at a minimum. With  $0''.075$  pixels, NICMOS Camera 2 gives reasonably well-sampled diffraction-limited images at around  $1.6\ \mu\text{m}$ .

At the time of the observations the understanding of the NICMOS instrument was in a very preliminary state, and as a result, during two of the four dither configurations the default positioning placed the OT on a detector column of very limited quantum efficiency. In addition, the observations were broken up by the scheduling program into two sessions, the second of which occurred immediately after the telescope had passed through the South Atlantic Anomaly, a region of particularly high particle background. Therefore, two of the four images show significant noise caused by persistent charge left by cosmic rays. These problems, combined with the early state of the calibration images has made the data less powerful, and our calibration less precise than nominal expectation. Nonetheless, the OT point-like source is easily visible in all of the data sets, with a signal-to-noise ratio of about 15 in a single 500-second exposure.

### 3. Results

The photometric calibration of the images was done using the synthetic photometry package SYNPHOT in IRAF/STSDAS. For STIS, given the broad-band response of the instrument, a power-law spectral shape with index  $\alpha_\nu \simeq 1$  was assumed, based on Keck spectrophotometry and on the photometric colors. This yields for the OT  $V = 23.45 \pm 0.15$  ( $1\sigma$ ) and  $R = 23.10 \pm 0.15$ . Although the STIS photometric calibration is still preliminary, we find agreement with ground-based imaging of other stars in the field at a level of 0.1 mag (Djorgovski 1997). For NICMOS, our calibration gives an OT magnitude of  $H = 20.6 \pm 0.3$ . However, as already noted, the NICMOS photometric calibration is still in a very preliminary state, and we have no corroborating ground-based data. The large error we have assigned reflects the uncertainty of the photometric calibration.

In the near-infrared, the faint galaxies located at North-East (G1) and North-West (G2) can be detected in an image smoothed with a boxcar of 4 pixels and are found to have fluxes of  $0.8 \pm 0.1\ \mu\text{Jy}$  ( $H = 22.8$ ) and  $1.9 \pm 0.1\ \mu\text{Jy}$  ( $H = 21.9$ ), respectively. Since the STIS CCD response peaks in the V band, their R magnitudes have been interpolated assuming a power-law spectrum consistent with the  $V - H$  color. The results are  $R = 24.8 \pm 0.2$  (G1) and  $R = 25.5 \pm 0.2$  (G2). G1 is extremely blue, as reported by Djorgovski et al. (1997), and the colors are consistent with a rapidly star-forming galaxy at any reasonable redshift. G2 is somewhat redder, but has the colors of a nearby late-type spiral galaxy whose spectrum has been shifted to  $z \sim 0.7$ . Therefore, either of these objects

could be responsible for the absorption seen in the Keck spectrum at  $z = 0.767$ . As we explain below, we doubt that either of these galaxies could produce the absorption system at  $z = 0.835$ , which appears to be caused by a dense interstellar medium in a low-ionization state.

The R band STIS magnitude lies within the  $1\sigma$  uncertainty of the extrapolation to June 2.5 of a power-law decay fit to earlier data. An R band measurement ( $R = 23.4$ ) taken at Keck after our HST observation (5 June) confirms this trend (see Figure 1). Under the assumption that this decay law correctly reflects the behavior of the OT, the lack of any evidence of flattening in this temporal descent allows us to put a  $3\sigma$  upper limit on an underlying galaxy of  $R=24.4$ . To further constrain the luminosity of an underlying galaxy, we have subtracted a scaled stellar point spread function (PSF), obtained from an earlier STIS image of the globular cluster  $\Omega$ -Cen. The residual, which is less than 10% of the flux of the star, is consistent with that expected due to changes in telescope focus and the necessity of using a PSF star translated from the position of the OT on the detector.

We further tested our ability to detect nebulosity by creating an artificial “compact galaxy” by convolving the PSF with a Gaussian of intrinsic FWHM =  $0''.15$ . Such an object would be just sufficiently extended to be distinguished from a point-like source in the Hubble Deep Field images. After subtracting a PSF, residuals are easily visible in the image if the “galaxy” is 1-2 magnitudes fainter than the OT, or  $R \simeq 24 - 25$ . They become difficult to discern when the galaxy’s magnitude is fainter than  $R \simeq 26$ . However, for  $R > 25.5$  one approaches a regime where a number of unresolved blue objects were found in the Hubble Deep Field: were one of those associated and well-aligned with the OT it would be subtracted out with the PSF.

As a final test we added the OT onto the image of G1 and again fit and subtracted a PSF. In this case the residuals were both immediately obvious to the eye and statistically significant. We therefore believe that any underlying galaxy must be no brighter than  $R = 24.5$ ; if it is an extended object with a scale size greater than a few tenths of an arcsecond, it must be fainter still. Thus, a source of the magnitude and shape of that reported for GRB970228 (Sahu et al. 1997a) would have been easily detected.

Similarly, after subtraction of a scaled artificial PSF, the NICMOS image is also consistent with sky noise statistics and we estimate any underlying, extended component must have  $H > 22.2$  within  $0''.4$  of the point-like source. Furthermore, if one uses ground-based I and K band measurements (Kopylov et al. 1997; Morris et al. 1997) obtained on May 13 to interpolate an H band magnitude and scale this value to the time of the NICMOS observations, according to a  $p \simeq 1.2$  power-law decay, one predicts a flux of  $3 \pm 1 \mu\text{Jy}$ , fainter than but in rough agreement with the NICMOS measurement of

$6.2 \pm 1.5 \mu\text{Jy}$ . This comparison is therefore consistent with our conclusion that a superposed galaxy could only contribute a small fraction of the total observed H band flux.

#### 4. Discussion

The absence of any obvious visible host galaxy is particularly striking given the detection of Mg I absorption and [O II] emission in the Keck spectra. The Mg I indicates that the absorbing medium is not highly excited and the [O II] implies that active star formation is occurring. While there are several galaxies with  $V > 24.5$  within a few arcseconds of the OT, this corresponds to a projected distance of tens of kiloparsecs at  $z = 0.8$ . It seems unlikely that either the high density or low excitation necessary for the Mg I line could be maintained this far out in a galactic halo – indeed of the 103 quasars in the compilation by Steidel and Sargent (1992), only 19 exhibit Mg I absorption lines, and none of these has rest frame line equivalent widths or ratios of Mg I to Mg II absorption as large as that seen in the spectrum of the OT of GRB970508. Therefore, we believe that the absorbing medium responsible for these lines is presently hidden by the light from the OT and is almost certainly the underlying host galaxy.

The implications of the redshift on the nature of the host are equally profound. Were the GRB at  $z \sim 2$  (the upper limit suggested by the Keck spectrum of the OT) the  $K$ -correction and cosmological dimming of the source would allow the host to be as bright as the knee of the galaxy luminosity function,  $L^*$ , and yet evade detection in both the STIS and NICMOS images. On the other hand, if the OT is located at  $z = 0.8$ , the host must be considerably fainter than  $L^*$ . The [O II] emission superposed on the OT continuum suggests that the host is rapidly star-forming, and therefore quite blue (and thus would have a negligible  $K$ -correction at this redshift). An apparent magnitude of  $R = 24.5$  then corresponds to an absolute blue magnitude of  $-18.6 \pm 0.5$ , where the error represents the uncertainty in the cosmological parameters.

One might be concerned, however, that we are not observing an optical source associated with GRB970508, but rather an extragalactic supernova or active galactic nucleus (AGN) located within the BeppoSAX positional error box. However, the Keck spectrum indicates that such an interloper would have to be at a minimum redshift of  $z = 0.8$ , and thus we would be observing its restframe ultraviolet emission. The absolute magnitude of a Type Ia supernova (the brightest type) in U band near maximum is  $\sim -20$  (Leibundgut & Tammann 1990). At a redshift of  $z = 0.8$ , this would produce an apparent R band magnitude of  $\sim 23.5$  or several magnitudes below the peak of the OT to GRB970508. If a supernova were at a higher redshift, the discrepancy between predicted and observed

magnitude would be even greater. In addition, the spectrum of the OT shows none of the strong, broad features so prominent in Type Ia supernovae (Panagia 1987). We therefore conclude that the OT is not an extragalactic supernova. The suggestion that the OT is an AGN appears equally unlikely. We know of no AGN that has exhibited behavior at all reminiscent of the regular, five magnitude power-law decline of this source. Rather, AGNs are characterized by irregular, unpredictable optical variability (see reviews by Clavel 1994; Wagner & Witzel 1995; Ulrich, Maraschi, & Urry 1997).

The upper limit to the host galaxy absolute magnitude,  $M_B = -18.6$ , estimated for a redshift of  $z = 0.8$ , corresponds to about one tenth of  $L^*$ . However it is now known that the star-formation rate in the universe was approximately a factor of ten higher at  $z \sim 1$  (Lilly et al. 1995), and that the majority of this star formation probably occurred in galaxies less luminous than  $L^*$  (see Babul & Ferguson 1996, and references therein for a discussion of this question). At least two models for the creation of GRBs – the merging of neutron star binaries (Narayan, Paczyński, & Piran 1992) and failed supernovae (Woosley 1993) – directly associate GRBs with the formation of massive stars. In the latter case, the GRBs would generally occur at the sites of star formation, while in the case of merging neutron stars, the kick given to the binary at the birth of the second neutron star could cause the binary to travel up to tens of kiloparsecs during the  $\lesssim 100$  million year timescale of the merger (Tutukov & Yungelson 1994).

If formation of GRBs is indeed tied to star formation, the location of these objects in relation to their hosts should provide strong clues to the nature of the birth mechanism. Furthermore, the rate of GRBs with redshift would increase far more rapidly than the co-moving volume of the universe, for it would be proportional to the rate of star formation multiplied by the co-moving volume. The cosmological density of GRBs should then follow the general rise and fall of star formation with redshift (Madau et al. 1996). Indeed, it appears possible that GRBs may eventually provide our best tool for measuring the star-formation history of the universe.

Although we may eventually find that GRB970508 does indeed lie in a faint, star-forming galaxy, at present the observations underline the longstanding issue of the lack of detected GRB host galaxies (Fenimore et al. 1993; Schaefer 1994; though see Larson 1997) and point to the necessity of pursuing deep and systematic studies of GRB environments. This will only be achieved through the dedication of significant observing time on HST as well as on large, ground-based optical telescopes.

We thank Bob Williams for allocating Director’s Discretionary time to this program. We would also like to express gratitude to S. Baum, I. Busko, J. Christensen, H. Ferguson,

J. Hayes, E. Huizinga, A. Roman and P. Stanley for their help in observation planning, and assistance with data reduction. We acknowledge the major efforts of the STIS and NICMOS Investigation Definition Teams, in building these powerful new instruments, and providing useful calibrations at such an early stage, and particularly thank R. Thompson and B. Woodgate. We benefitted from discussion with P. Caraveo, G. Djorgovski, D. Frail, G. Ghisellini, J. Gorosabel, P. Madau, K. Noll, M. O’Dowd, N. Panagia, R. Scarpa, C. Steidel, and C. M. Urry. C. Alcock, D. Dal Fiume, A. Guarnieri, J. Heise, L. Metcalfe are acknowledged for their support of this project. M. Feroci, L. Nicastro, E. Palazzi, and E. Pian acknowledge financial support from the Italian Space Agency (ASI).

**Authors’ note:** The reduced HST data discussed in this paper are available from [http://www.stsci.edu/~fruchter/GRB/data\\_970508](http://www.stsci.edu/~fruchter/GRB/data_970508).

## REFERENCES

- Babul, A., & Ferguson, H. 1996, *ApJ*, 458, 100
- Bond, H. E. 1997, *IAU Circ.* No. 6654
- Castro-Tirado, A. J., et al. 1997, *IAU Circ.* No. 6657
- Chevalier, C., & Ilovaisky, S. A. 1997, *IAU Circ.* No. 6663
- Clavel, J. 1994, in *Multi-Wavelength Continuum Emission of AGN*, eds. T. J.-L. Courvoisier and A. Blecha (Dordrecht: Kluwer), p.131
- Costa, E., et al. 1997a, *Nature*, 387, 783
- Costa, E., et al. 1997b, *IAU Circ.* No. 6649
- Djorgovski, S. G., et al. 1997, *Nature*, 387, 876
- Djorgovski, S. G. 1997, private communication
- Fenimore, E. E., et al. 1993, *Nature*, 366, 40
- Frail, D. A., Kulkarni, S. R., Nicastro, L., Feroci, M., & Taylor, G. B. 1997, *Nature*, 389, 261
- Fruchter, A. S., & Hook, R. N. 1997, *PASP*, submitted
- Fruchter, A. S., et al. 1997, in *Proc. of the 4th Gamma-Ray Burst Symposium*, Huntsville, 15-20 September 1997, in press
- Galama, T. J., et al. 1997, *IAU Circ.* No. 6655
- Garcia, M., Moraru, D., McClintock, J., Robinson, C. R., Kouveliotou, C., & van Paradijs, J. 1997, *IAU Circ.* No. 6661
- Groot, P. J., et al. 1997, *IAU Circ.* No. 6660
- Heise, J., et al. 1997, *IAU Circ.* No. 6654
- Hurley, K. 1997, private communication
- Klebesadel, R. W., Strong, I. B., & Olson, R. A. 1973, *ApJ*, 182, L85
- Kopylov, A. I., et al. 1997, in *Proc. of the 4th Gamma-Ray Burst Symposium*, Huntsville, 15-20 September 1997, in press
- Kouveliotou, C., et al. 1997, *IAU Circ.* No. 6660
- Lamb, D. Q. 1995, *PASP*, 107, 1152
- Larson, S. B. 1997, *ApJ*, 491, in press
- Leibundgut, B., & Tammann, G. A. 1990, *A&A*, 230, 81

- Lilly, S. J., Tresse, L., Hammer, F., Crampton, D., & Le Fevre, O. 1995, *ApJ*, 455, 108
- Madau, P., Ferguson, H. C., Dickinson, M. E., Giavalisco, M., Steidel, C. C., & Fruchter, A. S. 1996, *MNRAS*, 283, 1388
- Meegan, C. A., et al. 1996, *ApJS*, 106, 65
- Metzger, R. M., Djorgovski, S. G., Kulkarni, S. R., Steidel, C. C., Adelberger, K. L., Frail, D. A., Costa, E., & Frontera, F. 1997a, *Nature*, 387, 879
- Metzger, R. M., Cohen, J. G., Chaffee, F. H., & Blandford, R. D. 1997b, *IAU Circ. No.* 6676
- Mignoli, M., et al. 1997, *IAU Circ. No.* 6661
- Morris, M., Mastrodemos, N., Zuckerman, B., McCarthy, C., Becklin, E., Lowrance, P., Chary, R., & Barnbaum, C. 1997, *IAU Circ. No.* 6666
- Narayan, R., Paczyński, B., & Piran, T. 1992, *ApJ*, 395, L83
- Paczynski, B. 1995, *PASP*, 107, 1167
- Panagia, N. 1987, *NATO ASI on “High Energy Phenomena in Collapsed Objects”*, ed. F. Pacini (Dordrecht-Holland), p. 33
- Pedersen, H., et al. 1998, *ApJ*, 496, in press
- Piro, L., et al. 1997a, *IAU Circ. No.* 6617
- Piro, L., et al. 1997b, *IAU Circ. No.* 6656
- Piro, L., et al. 1997c, *A&AL*, submitted
- Sahu, K. C., et al. 1997a, *Nature*, 387, 476
- Sahu, K. C., et al. 1997b, *ApJL*, in press
- Schaefer, B., et al. 1997, *IAU Circ. No.* 6658
- Schaefer, B. 1994, in *AIP Conf. Proc. 307, Gamma-Ray Bursts*, ed. G. J. Fishman, J. J. Brainerd, and K. Hurley (New York: AIP), p. 382
- Steidel, C. C., & Sargent, W. L. W. 1992, *ApJS*, 80, 1
- Tutukov, A. V., & Yungelson, L. R. 1994, *MNRAS*, 268, 871
- Ulrich, M.-H., Maraschi, L., & Urry, C. M. 1997, *ARA&A*, in press
- van Paradijs, J., et al. 1997, *Nature*, 386, 686
- Wagner, S. J., & Witzel, A. 1995, *ARA&A*, 33, 163
- Williams, R. E., et al. 1996, *AJ*, 112, 1335

Woosley, S. E. 1993, *ApJ*, 405, 273

### Figure Captions

Fig. 1.— Light curve of the OT of GRB970508. Photometry is taken from Pedersen et al. (1998), Castro-Tirado et al. (1997), Sahu et al. (1997b, the R magnitudes have been interpolated from the V and I magnitudes assuming a power-law spectrum), Djorgovski et al. (1997), Galama et al. (1997), Schaefer et al. (1997), Kopylov et al. (1997), Mignoli et al. (1997), Groot et al. (1997), Garcia et al. (1997), Chevalier & Ilovaiski (1997), Metzger et al. (1997b) (open circles) and HST-STIS (filled circle). All magnitudes have been converted to Kron-Cousins R. Uncertainties have been rounded up to 0.1 magnitudes when smaller values were reported in the literature, to take into account possible systematic photometric offsets due to instrumental differences. The power-law fit to the 10.5-22 May data (solid line) is reported along with the  $1\sigma$  uncertainty range (dashed lines).

Fig. 2.— The HST-STIS image of the field surrounding the OT of GRB970508. A region of  $22''.5 \times 16''.25$  is shown. The arrows indicate the North and East directions. The two galaxies at  $\sim 5''$  distance from the OT, referred to in the text as G1 and G2, are on the upper left and upper right, respectively. The final frame was created using  $0''.025$  pixels, one-half the size, in linear dimension, of the original STIS pixels. The image has a FWHM of  $0''.09$  and a limiting  $10\sigma$  sensitivity in a  $0''.5 \times 0''.5$  box of  $V = 27.4$ . The HST-NICMOS image shows only a moderate signal-to-noise point-like source at the position of the OT, and has therefore not been displayed.



